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Estimating PM10 and FP (Fine Particulate) Background Concentrations from TSP (Total Suspended Particulate) and Other Measurements

PEDCo-Environmental, Inc., Golden, CO

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16. ABSTRACT

This document has been developed in response to the recognition that there may be a number of States revising their State Implementation Plans (SIP) for Particulate Matter (PM) following the recently proposed revision to the National Ambient Air Quality Standards (NAAQS) for PM_{10}. State and local agencies need a method of estimating background for size-fractioned particulate as part of SIP development for PM_{10} and Fine Particulate (FP). The method for estimating background concentration that is specified in Section 51.13c of Federal regulations uses a concentration measured at a nonurban site in or near the analysis area that is unaffected by near emission sources. This document provides information on how to estimate a PM_{10} background value from other measurements when PM_{10} monitoring data are not available.

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SECTION 1
INTRODUCTION

BACKGROUND

This document has been developed in response to the recognition that there may be a number of States revising their State Implementation Plan (SIP) for particulate matter (PM) in light of the recently proposed revision to the National Ambient Air Quality Standards (NAAQS) for PM_{10}. State and local agencies need a method of estimating background for size-fractionated particulate as part of SIP development for PM_{10} and fine particulate (FP). The method for estimating background concentration that is specified in Federal regulations (Section 51.13c) is to use a concentration measured at a nonurban site in or near the analysis area that is unaffected by nearby emission sources.

Most regional monitoring networks contain one or more designated background hivol sites. However, there are relatively few size-fractionated particulate samplers measuring PM_{10} and FP compared with those measuring TSP; and almost all of the former are in urban locations. Therefore, states may not have direct measurements of PM_{10} or FP background available when they prepare their SIP's.

This document provides information on how to estimate a PM_{10} background value from other measurements when PM_{10} monitoring data are not available. Two time frames are considered, annual and 24-hour (denoted herein as high 24-hour). The discussion relating to the 24-hour situation should be thought of as a means of adjusting a 24-hour Total Suspended Particulate (TSP) or Inhalable Particulate (IP) background observation to PM_{10} for use with a 24-hour design concentration; and likewise for the annual situation for adjusting an annual TSP or IP background to PM_{10} for use with an annual design concentration.

PURPOSE

The purpose of this study is to evaluate several indirect methods of estimating PM_{10} and FP concentrations at background locations from other available measurements, and to rank these alternative methods according to their ability to accurately estimate background levels in diverse geographic areas. FP is included in this document because it may be helpful in estimating the long range transport component of measured data or in determining the causes of visibility impairment.

The methods evaluated are based on relatively simple relationships that might be shown to exist (e.g., PM_{10} annual average = constant percentage of TSP annual average). The methods to be evaluated are listed in Table 1. Further descriptions of them can be found in Section 3.

Several of these methods have been examined previously for predicting PM_{10} and/or FP concentrations at any location, not just at remote nonurban locations.[1-3] The present effort has attempted to use or build on these past analyses, rather than arbitrarily selecting possible predictive models.

SCOPE

As indicated in Table 1, several different background estimates are desired--annual average (ann av) PM_{10}, high 24-h PM_{10}, ann av FP, and high 24-h FP. In this analysis, the observed max 24-h data are used to develop the high 24-h methodology. In practice the 24-h background may not be based on the max concentrations. In addition, a further breakdown of these previously mentioned four background concentrations into regionally-generated and long-range transport components would be of value in the SIP development process. However, with the resources available to the present study, this additional breakdown of estimated background concentrations was not attempted.

The 13 methods in Table 1 are evaluated separately for their ability to predict each of the four background values, or as many

TABLE 1. METHODS OF ESTIMATING PM_{10} AND FP BACKGROUND

Estimating method	Background levels for which applicable[a]			
	Ann av PM_{10}	High 24-h PM_{10}	Ann av FP	High 24-h FP
1. Use dichotomous IP data, adjust total IP to PM_{10}	x	x	b	b
2. TSP at background site times constant ratio	x	x	x	x
3. Use IP data from nearby suburban residential site	x	x	x	x
4. IP at nearby suburban residential site times ratio of IP to TSP values at surburban background sites	x	x		
5. IP sulfates and nitrates at suburban residential site times constant ratio	x	c	x	c
6. TSP sulfates and nitrates at background site times constant ratio	x		x	
7. Size-Selective Inlet concentration at background site times constant ratio	x	x		
8. Prediction of high 24-h value as constant ratio of corresponding ann av concentration		x		x
9. High 24-h IP times constant ratio				x
10. Linear function of visibility (extinction)	x	c	x	c
11. Linear function of (visibility + TSP)	x	c	x	c
12. Default values for FP in the west			x	
13. Average of values obtained from two or more of the above methods	x		x	x

[a] The "high 24-h" methods are applicable when exceedances of the short term NAAQS are of interest.
[b] Direct measurement obtained from IP dichotomous sampler.
[c] Inadequate data available to evaluate.

of the four to which the method is applicable and for which adequate data are available. It is possible that different methods may be recommended for estimating the different background values.

ORGANIZATION

Evaluation and ranking of the 13 methods were performed primarily on the basis of how closely the background values predicted by each method match a set of measured background values from EPA's IP Network. "Closeness" of the predictions is to be determined by the standard error of estimate (the standard deviation of differences between measured and predicted values). The evaluation/ranking system is described in detail in Section 2.

The lack of PM_{10} and FP background data is a problem not only for the states in preparing their SIP's, but also for use as a comprehensive data base for the present analysis. The small data base, low concentrations at background sites (near the laboratory analytical thresholds), differences in sample handling and analysis procedures inherent in a national data set, and significant seasonal variations found in fine particulate all contribute to increased standard errors for the estimating methods.

Because of these deficiencies in the available data base, some qualitative factors are also considered in evaluating and ranking the methods. The calculated standard errors and judgmental adjustments are presented in Section 4, Results.

In the final section, Conclusions and Recommendations, the acceptable predictive methods are ranked for each type of background concentration.

SECTION 2
METHODOLOGY AND DATA BASE

METHODOLOGY

Evaluation Procedure

The procedure used to evaluate alternative background prediction models must be capable of ranking them in some sort of systematic manner. Consequently, the procedure should be equally applicable to all methods and capable of being employed consistently to different types of data sets (e.g., TSP data, SO_4 data, visibility data).

Previous work has been done in evaluating methods of estimating inhalable particulate (IP) and FP concentrations at any location based on other available particulate air quality data.[1,2,4] One means of comparing different methods in this previous work was by their standard errors of estimate, $S_{y,x}$.

The standard error of estimate is simply the standard deviation of the differences between observed (measured) and predicted values in a paired data set, or the average difference adjusted for degrees of freedom. In this case, the observed values are either annual average or 24-hour IP or FP values at background sites and the predicted values are from the various estimating methods. In equation form,

$$S_{y,x} = \sqrt{\frac{\Sigma (Y_m - Y_p)^2}{n-k}}$$

where Y_m = Measured concentrations, $\mu g/m^3$
Y_p = Concentrations predicted by estimating method, $\mu g/m^3$
n = Number of data pairs
k = Degrees of freedom lost (1 if method is a ratio of values, 2 if method is linear regression equation)

To facilitate comparisons between methods, the standard error of estimate can be expressed as a percent by dividing by the mean measured value of IP or FP: $S_{y,x}/\bar{y}_m$. Two separate tests of the variation in $S_{y,x}$ with IP and FP levels have both shown that the errors are proportional to IP and FP values rather than a constant error for all levels of IP and FP.[2,3] Therefore, the percent standard error values are as representative a measure of performance as the absolute $S_{y,x}$ values and are more directly comparable.

The lower the percent standard error for an estimating method, the more precise it is. This evaluation procedure appears to satisfy all the requirements specified above--it is systematic, can be used to rank the alternatives, can be used with all methods, and can be employed with any type of independent data sets.

There is always the danger of "overprediction" when the same data set (group of background sites) is used to derive the standard error that was used to establish the predictive relationship. Therefore, other data sets besides the EPA IP network have been located and used where possible to get an unbiased measure of standard error for each method. These independent data sets are described later in this section. They are particularly important for statistically-derived models to demonstrate that the models are applicable to different situations (i.e., locations) than the ones from which they were developed.

Quantifying Predictive Models

As indicated in Section 3, all the predictive models are relatively simple. For methods which require a constant ratio to predict the PM_{10} or FP background value, the constant can be obtained either from the slope of a linear regression analysis or from the average ratio of individual data pairs. If the constants produced by linear regression and the average ratio have approximately equal predictive ability (as measured by percent $S_{y,x}$), the average ratio is preferable because it is simpler to calculate and does not contain the y-intercept term.

The IP and FP estimation models evaluated in previous studies all had equal or better predictive abilities with average ratio constants.[1,2] In the present study, the average ratio was used almost exclusively to quantify constants for predictive models.

Stratification of data, usually by geographic area, with different constants for each subset, has also been used in previous work to improve a model's overall predictive power.[1] Constants for each subset are obtained in the same manner as above and the model or method is still easily evaluated by the percent $S_{y,x}$ procedure. Because of the small size of the data bases for background sites, the only stratification that was performed in the present study was dividing sites into eastern (E) and western (W) subsets. This was routinely done in evaluating each estimating method. The division between eastern and western sites was generally along the Mississippi River. Stratification by E/W is based primarily on the distinctly different sulfate and visibility levels observed in these two areas.[3]

If the percent standard error is not substantially reduced by stratification or if the constant ratios for the E/W subsets are not significantly different, there is no reason to use stratified data. The appropriate statistical test to determine whether the constants for the two subsets are significantly different is the t-test for difference between means (two-tailed), in which the difference in constants must be greater than the appropriate tabled t-value times the standard deviation of the difference in means in order to be significant:

$$\bar{R}_E - \bar{R}_W > (t_{n-2,x}) \sqrt{\frac{S_E^2}{n_E} + \frac{S_W^2}{n_W}}$$

Adjustments to Ranking

The standard error of estimate provides a readily computable, systematic procedure for ranking all the background estimating methods. As with most strictly numerical rating systems,

it cannot be easily adapted to accept nonquantitative input. Therefore, some manual adjustments to the rankings according to $S_{y,x}$ have been made based on such other considerations as:

1. Maintaining a consistent order of methods for the four background values being estimated (ann av PM_{10}, high 24-h PM_{10}, ann av FP, high 24-h FP).
2. The potential for measurement error is large for the substitute air quality measurement.
3. Predictions depend heavily on the site designation (e.g., suburban residential) assigned to the data set used in the method.
4. The method is only applicable in the east or west.

Whenever an adjustment of the rankings reported in Section 4 is made, it is noted and reasons for the change are given.

DATA BASE

Four different data sets that have at least one year's IP and FP data from sites with a wide geographic distribution were identified:

- EPA's IP network (5/1979 - 12/1982)
- Sulfate Regional Experiment (SURE) sites[1]
- Western Particulate Characterization Study
- Previously published particulate data compiled in a 1982 PEDCo report[5]

Sampling methods, time periods, site locations, and other information on these four data sets are summarized in Table 2.

Samplers in these networks were originally designed to produce sample fractions <2.5 μm (FP) and 2.5 to 15 μm (coarse fraction of IP), although subsequent evaluation of the SURE samplers indicated a wind speed-sensitive upper cut point that averaged closer to 10 μm than 15 μm. However, the point to be emphasized is that there are no large-scale long-term data sets with direct measurements of PM_{10}. Analyses of the PM_{10} to IP ratio performed to date show a fairly consistent relationship, as discussed in Section 3. Variations in the results for these earlier studies can be attributed to the different data bases

TABLE 2. AVAILABLE IP AND FP DATA SETS

Characteristics	Data set: EPA IP	SURE	WPCS	Other published
Location of network	Nationwide	Eastern U.S.	8 western states	Oregon, St. Louis, other
No. of sites in network	165	9	40	77
No. of background sites	16	9	40	12
Criteria for location of background sites	Nonurban, but usually to help characterize levels for an urban area	Nonurban, designed to find regional SO_4 levels	Remote, mainly National Park Service lands (Class 1 areas)	NA[a]
Sampling equipment				
TSP	Hivol	Hivol	None	Hivol
IP	SSI, dichot	SF[b]	SF	SSI, dichot
FP	Dichot	SF	SF	Dichot
Network operating period	May 1979 to December 1982	Six 1-month periods from 8/77 to 10/78	7/79 to 10/81	Various times between 1975 and 1979
Sample length, h	24	24 for hivol 3 for SF	72	24
Sampling frequency	Every 6th day	NA	2/week	Various
Other data available				
Max concentrations	Yes	Yes	No	No
Individual data values	Yes	No	No	No
Nearby suburban sites	Yes	No	No	Yes
Sulfate, nitrate	Yes	No	No	No

[a] NA = not available.
[b] SF = stacked filter

used. There appears to be support in the literature for use of a corrected IP value as an acceptable measurement of PM_{10} concentration.[6,7]

IP Network

EPA's IP Network data were selected as the primary data set for several reasons. These data were collected at sites nationwide with uniform equipment and procedures, and have been subjected to fairly rigorous validation both internally and by external users. The single characteristic of the data base that sets it apart from the others available is that it contains all the other simultaneous sampling data needed to test the proposed estimating methods, i.e., suburban sites in the same regions as nonurban sites, sulfate and nitrate data, and hivol and SSI data at the same sites as dichotomous sampler IP data.

Sites in the IP Network were selected as reasonable background locations based on firsthand knowledge of the sites' surroundings. Most were classified as rural or remote in their site descriptions, but a few were listed as suburban residential because they were located in developed areas. With a few exceptions, the 16 sites identified as background sites were not influenced by local sources but were impacted slightly by their proximity to an urban area.

The IP Network data extracted for use in the analyses were days on which both TSP and dichotomous sampler IP and FP concentrations were reported. Available data extended from mid 1979 through 1982, but sites and equipment were generally not active for that entire period. Because of the intermittent nature of the simultaneous TSP-IP data, a single summary rather than annual summaries was developed for each site. These total sample sizes were generally in the range of 30 to 70 samples, consistent with the number of samples in an annual data set for a continually-operated site sampling every sixth day. Summary data for the 16 IP Network background sites are presented in Table 3.

These data had already been subjected to an EPA validation process. The few outliers found are already removed from the

TABLE 3. SUMMARY OF EPA'S IP NETWORK DATA[a]

Site	Arithmetic mean, $\mu g/m^3$				Max 24-h concentration, $\mu g/m^3$		
	No. of samples	TSP	Total IP	FP	TSP	Total IP	FP
Mountain Brook, AL	73	53.4	28.0	19.2	91.8	55.0	37.3
Carefree, AZ	61	45.7	23.3	7.0	98.2	68.0	12.1
Litchfield, CT	36	35.5	16.2	10.1	69.7	67.3	55.8
Braidwood, IL	42	61.6	27.1	16.4	100.5	68.6	38.6
Marshalltown, IA	56	47.8	31.6	14.5	123.6	80.2	23.0
Acadia National Park, ME	30	19.7	12.7	8.3	44.6	38.0	33.1
Winnemucca, NV	67	55.4	29.7	8.7	267.2	158.5	21.3
Angola, NY	50	36.5	26.5	18.0	84.6	59.8	48.1
Research Triangle Park 101, NC	37	43.6	23.7	19.0	82.0	40.8	31.3
Research Triangle Park 102, NC	63	37.1	23.6	15.1	86.4	60.3	32.4
Medina, OH	24	48.2	31.3	19.9	80.3	49.8	40.6
Sauvie Isl., OR	65	35.3	27.6	13.5	167.7	76.5	43.0
Clint, TX	87	77.9	49.6	13.3	259.3	181.1	31.0
Seabrook, TX	37	54.3	33.7	15.6	87.8	73.6	43.1
Reston, VA	94	44.4	27.5	18.8	79.3	66.0	49.5
Sauvie 2, OR	51	40.5	27.0	14.1		Not used	-

[a] Data are representative of samples taken during the time period May 1979-December 1982. Actual data for each site are a subset of this period.

values shown in Table 3. These deletions are the same as those removed by other users and are based on the criteria IP/TSP >1.5 or TSP/IP >4 while FP/IP >0.6.[2]

Other researchers have analyzed the IP Network data for relationships between TSP and IP or FP.[1,6,7] The earlier analyses did not include 1982 data, which only recently were released. Their data selection processes were also slightly different from those used in the present study. However, the important observation in this case is that the conclusions of these size-fractionated particulate studies may all be generally consistent largely because they are derived from essentially the same data base. In this analysis, a new subgrouping, rural background sites, was considered for the first time.

Other Data Sets

The three other IP/FP data sets identified are important as independent data sets for checking the standard errors of predictive models developed with the IP Network data base. All three were used for that purpose in testing some of the methods. Because the other data sets did not have much additional simultaneous particulate sampling data such as TSP or SSI values, they could not be utilized to evaluate all methods.

Summary data for SURE, Western Particulate Characterization Study, and PEDCo's compilation are presented in Tables 4, 5, and 6, respectively.

TABLE 4. SUMMARY DATA FROM NINE SURE SITES

Site	15-month arithmetic mean, $\mu g/m^3$			Max 24-h concentration, $\mu g/m^3$		
	TSP	IP	FP	TSP	IP	FP
Montague, MA	22	23	17	82	92	68
Scranton, PA	58	29	18	217	102	81
Indian River, DE	35	29	19	92	90	63
Duncan Falls, OH	42	31	20	163	76	47
Rockport, IN	55	37	23	197	120	86
Giles Co., TN	43	29	19	93[a]	65	51
Ft. Wayne, IN	40	28	20	101	84	61
Research Triangle Park, NC	36	28	20	99	69	50
Lewisburg, WV	30	22	16	66	47	53

[a] Removed value of 254 $\mu g/m^3$ as outlier according to criteria TSP/IP >4/1 while FP/IP >0.6.

Source: Reference 1, pp. 6-8 and 6-9.

TABLE 5. SUMMARY DATA FROM WESTERN PARTICULATE CHARACTERIZATION STUDY

Site[a]	27-month arithmetic mean, µg/m³		Site[a]	27-month arithmetic mean, µg/m³	
	IP	FP		IP	FP
Murphy Lake, MT	9.1	4.8	Fish Springs, NWR, UT	8.6	2.4
Malta Airport, MT	12.4	3.3	Brown's Park NWR, CP	7.2	2.7
Medicine Lake, MT	12.5	4.1	Rocky Mountain NP, CO	6.1	2.6
Upper Souris NWR, ND	17.7	4.6	Cedar Mountain, UT	7.8	2.9
Belt Creek RS, MT	5.8	2.4	Delta Co. Airport, CO	13.9	3.7
Jordan Airport, MT	23.8	4.5	SAC Base, CO	11.9	4.1
T. Roosevelt NMP, ND	12.9	4.1	Bryce Canyon NP, UT	7.1	2.9
Bald Hill Dam, ND	17.5	4.3	Canyonlands NP, UT	7.3	2.7
Big Hole Valley, MT	5.3	2.2	Great Sand Dunes NM, CO	8.0	2.4
Bluewater, MT	9.0	2.9	Grand Canyon NP, AZ	6.4	2.5
Odell's Ranch, MT	14.0	2.9	Chaco Canyon NM, NM	8.0	2.8
Lake Hiddenwood, SD	12.7	3.8	Ft. Union, NM, NM	7.2	2.9
Yellowstone NP, WY	4.3	1.9	Montezuma Castle NM, AZ	13.2	4.4
Buffalo Airport, WY	12.0	3.0	Petrified Forest NP, AZ	7.3	3.2
Mt. Rushmore, SD	7.8	2.9	Grand Quivera NM, NM	9.4	3.2
Lake Andes NWR, SD	19.0	5.2	Orgon Pipe Cactus NM, AZ	15.2	5.0
Lander Airport, WY	13.5	4.2	Tonto NM, AZ	12.1	4.8
Ft. Laramie, WY	12.5	3.7	Gila Cliff Dw. NM, NM	8.0	3.7
Fossil Butte NM, WY	9.0	3.5	Carlsbad Caverns NP, NM	12.1	3.9
Saratoga, WY	7.9	2.8	Ft. Bowie, AZ	12.6	4.7

[a] NWR = National Wildlife Refuge
RS = Ranger Station
NMP = National Memorial Park
NP = National Park
NM = National Monument

TABLE 6. SUMMARY DATA FROM PEDCo'S COMPILATION

Site	No. of samples	Arithmetic mean, $\mu g/m^3$		
		TSP	IP	FP
Anaconda, MT	>200[a]	52.2	39.3	15.5
Dodge Rd., OR	NS	27.2	14.7	ND
Carus, OR	NS[b]	32.3	ND[c]	16.2
Lebanon, OR	>200[a]	43.3	ND	13.1
Corvallis, OR	>200[a]	32.3	ND	15.5
St. Louis 1, MO	>200[a]	54	31	16
St. Louis 2, MO	>200[a]	55	33	17
St. Louis 3, MO	>200[a]	53	29	16
St. Louis 4, MO	60	60	40	ND
St. Louis 5, MO	60	68	35	ND
St. Louis 6, MO	60	60	34	ND
St. Louis 7, MO	60	55	28	ND
Angola, NY	NS	45.9	33.0	ND
Sterling Forest, NY	NS	22.5	15.9	ND

[a] The actual number of samples for this site was not available in the reference. This value is a conservative estimate based on data in the reference and other project files.

[b] NS = Not specified.
[c] ND = No data.

Source: Reference 4, pp. 42-46.

SECTION 3
DESCRIPTION OF ESTIMATING METHODS

There is a theoretical or logical basis for each of the methods of estimating background described below. None of these methods were originally proposed as a result of searching a data set for any possible correlation between predicted and observed background PM_{10}. Instead, all were originally proposed on the belief that they have some logical underlying physical basis. Several methods in addition to the 13 described here were proposed, but judged to be too complicated or no data were available with which to evaluate them. An example of a method which failed on both counts is synthesizing a background data set from two or more sites located on the perimeter of an urban area by using the concentration from the site that was generally upwind of the urban area on each sampling day.[8]

For each of the methods, a similar format has been employed. Each subsection describes the basis for the method, how it would be applied, data requirements, and problems that might be encountered.

METHOD 1--DICHOTOMOUS SAMPLER DATA

Short of measurement with a PM_{10} dichotomous sampler, the IP dichotomous sampler is the most direct measurement of PM_{10} and FP. The main difference in the two samplers is inlet construction. Limited side-by-side testing of the IP dichot and PM_{10} dichot samplers in the EPA IP Network has shown that the FP fraction measured by the two samplers is the same. Several researchers have analyzed these limited data; they have concluded that there is a fairly consistent relationship between PM_{10} and IP.[1,2,4,9] Values cited in these 1981 references for PM_{10} range from about 70 to 90 percent of IP.

The same data set has been used in this study to evaluate this predictive method, which is obviously a shortcoming. These annual data are shown in Appendix Table A-1.

If IP dichot data are available at a background site in the region, they undoubtedly provide a better estimate of background than any of the other methods described in this section, especially with the direct measurement of FP.

The basic relationship to be evaluated for this method is of the form:

$$PM_{10} = K(IP)$$

where PM_{10} concentrations can be approximated by a constant times the measured IP concentrations.

An alternative measurement of IP can be obtained with a high volume sampler equipped with a size selective inlet (SSI) and utilizing quartz filters. This device was used in EPA's IP Network and the inlet can be modified to measure PM_{10} directly as with the dichotomous sampler.

METHOD 2--TSP TIMES CONSTANT RATIO

Because of the large number of background sites with TSP data, it would be desirable to estimate PM_{10} as a constant fraction of TSP. [i.e. with an equation of the form $PM_{10} = K(TSP)$]. This method has been investigated more than any of the others. FP and PM_{10} are both size fractions that are included within the TSP sample, so there should be some correlation between TSP and either PM_{10} or FP data at a given site. However, particles larger and smaller than about 2 μm are generated by completely different mechanisms (sources), so there would not necessarily be a strong correlation at different sites between FP and TSP levels.

The constant ratio between FP or PM_{10} and TSP must be evaluated for both 24-h concentrations and annual averages. In testing for a relationship between maximum measured 24-h concentrations of a size fraction and TSP, several combinations of data could be used:

Max TSP value in data set - Max PM_{10} or FP value in data set

Max TSP value in data set - PM_{10} or FP value on day of max TSP

Max PM_{10} or FP value - TSP value on day of max size fraction

In general, the concept from the first of these combinations has been used in testing. Since the basic thrust of this method is to calculate the high PM_{10} 24-hour value from measured TSP data, this is the only combination that is practical. Only 6 of the 16 sites evaluated for this method had both maximum measured values (TSP and PM_{10} or FP) occurring on the same day. Consequently, evaluation of the second combination (max TSP and measured PM_{10} or FP) would generally underestimate the high PM_{10} or FP value. Alternatively, with only TSP data it would be impossible for the user to select the TSP value that would be associated with the high PM_{10} or FP value (third combination). With the first combination the analyst would merely search the measured TSP data for the highest measured value and apply the conversion constant to calculate the high PM_{10} or FP value.

For PM_{10}, the ratio of IP/TSP was calculated for the five highest measured IP concentrations at each site. In all cases, the highest measured TSP concentration occurred on one of these five days. Next, the average IP/TSP ratio was calculated for each of the five highest days. The mean ratio (K) for a subgroup of sites was then calculated from the individual site means.

For FP 24-hour concentrations, the ratios between the highest measured FP and TSP concentrations were calculated for each site. Then the average ratio (K) was calculated for each subgroup (E and W).

The corresponding data sets for FP, IP and TSP were presented in Tables 3 through 6. Analysis results are shown in Appendix Table A-2 through A-4.

The major problem with evaluating this and all subsequent predictive methods is the lack of PM_{10} data. Therefore, based on the results of PM_{10}-IP analyses, IP has been used as a surrogate

for PM_{10} in all the evaluations of estimating methods (except Method 1).

METHOD 3--NEARBY SUBURBAN RESIDENTIAL SITE DATA

It may be that the types of localized sources in suburban residential areas primarily increase concentrations of large particle-size particulates, but do not elevate IP or FP substantially above background levels. Thus, this method uses the suburban residential IP and FP concentrations as estimates of background (i.e. IP background = IP suburban). It is evaluated by comparing the rural background measurements to suburban residential sites in the same analysis area.

A problem with this method is the dependence of resulting estimates on proper site designation and on proximity of the site to large sources of fine or coarse IP-size particulate.

METHOD 4--NEARBY SUBURBAN RESIDENTIAL VALUE TIMES $TSP_{rural}/TSP_{suburban}$

Although the activity-related fugitive sources that are dominant in suburban residential areas might not raise FP concentrations much above background, they probably have some impact on IP. One method to compensate for this impact, using available data, is to reduce IP concentrations at a suburban site by the ratio of TSP concentrations at the background and suburban site [IP background = IP suburban$(TSP_{rural}/TSP_{suburban})$]. Obviously, this method would only be applicable for estimating IP background.

A potential problem is that the method requires three separate concurrent particulate measurements to generate this estimate. Thus, the chance of obtaining an anomalous prediction is tripled compared with a method that relies on only one particulate value.

METHOD 5--IP SULFATES AND NITRATES AT SUBURBAN RESIDENTIAL SITE TIMES CONSTANT RATIO

The hypothesis underlying this method is that sulfate and nitrate concentrations at a suburban residential site are

probably less likely to be elevated over background levels than are any of the other particulate measurements. The unknown factor is whether a consistent ratio of sulfates plus nitrates to either IP or FP exists at sites in different geographic areas. This evaluation should determine whether sulfates and nitrates make up a fairly constant fraction of IP or FP. The basic relationships to be evaluated are of the form: K = (suburban IP SO_4 + NO_3)/background IP and K = (suburban FP SO_4 + NO_3)/background FP.

Insufficient sulfate/nitrate data for specific days that corresponded with IP and FP data at background sites were available in the IP Network to perform this evaluation for max 24-h IP or FP concentrations. This also indicates a lack of correspondence in the annual data, which injects another source of error into the estimates.

METHOD 6--TSP SULFATES AND NITRATES AT BACKGROUND SITE TIMES CONSTANT RATIO

Hivols collect large particles and do not fractionate them. However, most sulfates and nitrates are fine particles and totals for these two constituents should not be much greater in TSP than in IP. The major advantage of starting with TSP sulfates and nitrates is that these samples are available at background sites, negating the need for assumptions of uniform concentrations over large parts of the analysis area. The question of whether a consistent ratio of sulfates plus nitrates (in TSP) to IP or FP exists at sites in different geographic areas is the same as in the preceding method. The equations to be evaluated are: K = (TSP SO_4 + NO_3 background)/IP background, and K = (TSP SO_4 + NO_3)/FP background. Also, the lack of sulfate/nitrate data for specific days precludes the evaluation of this method for max 24-h concentrations.

An additional source of error in this method is sulfate artifact formation (due to the adsorption of SO_2 and its oxidation to $SO_4^=$) on the hivol glass fiber filters.

METHOD 7--SIZE SELECTIVE INLET (SSI) TIMES CONSTANT RATIO

The hivol with a size-selective inlet (SSI) collects sub 15 μm particles without providing an FP size cut. Because of apparent problems with artifact formation on the glass fiber hivol filters, IP measured with an SSI is almost always larger than IP measured with a dichot. To maintain consistency, it is recommended that SSI samples be taken on quartz filters. For samples taken on quartz filters the data can be treated the same as for the dichot.

If IP measurements taken with an SSI on glass fiber filters are the only available particulate background samples for an analysis area (an unlikely situation), they could be converted to equivalent dichot IP measurements by multiplying by a constant reduction factor [i.e. IP background = K(SSI background)]. This then becomes an estimating method for IP; it has not been evaluated for predicting FP.

The annual factor (K) was calculated for each of 10 sites based on the average ratio of dichot IP/SSI concentrations for simultaneous measurements. Then the overall average factor was calculated as the mean of the 10 individual factors.

The 24-hour factor was calculated as the average ratio of high dichot $IP_{24\text{-}h}/SSI_{24\text{-}h}$ for measured values. The same rationale outlined for Method 2 was followed in the selection of maximum measured values for this method.

METHOD 8--MAX 24-H BACKGROUND VALUE AS CONSTANT RATIO OF CORRESPONDING ANNUAL AVERAGE CONCENTRATION

If background concentrations are in fact primarily due to long-range transport and local natural sources, the lognormal distributions of daily values at different sites should have similar slopes and the ratio between a 98-percentile (maximum measured) and annual mean value should be fairly consistent from site to site (i.e. K = high 24-h IP/mean IP). This relationship has been found for TSP and may be applicable to IP^{10}. The average ratio for use in this model can easily be determined from the 16 background sites in the IP Network.

This method is only applicable to the prediction of high 24-h background values. Also, since this prediction is based on a concentration that is already an estimate, it will contain the error in estimating the underlying ann av value as well as the error associated with the ratio of max to mean concentration.

METHOD 9--24-H IP TIMES CONSTANT RATIO

Carrying the potential interrelationships among the background values to be estimated one step further, the high FP concentration may well be closely related to the high IP concentration. If the high 24-h IP is predicted by a method not applicable to FP values (e.g., from SSI data), the ratio between FP and IP could provide a simple method for obtaining the high 24-h FP value. The basic relationship to be evaluated is of the form 24-h FP = K(24-h IP).

As with the previous method, the average ratio to use in the model can be obtained from IP Network data. Also, the predicted FP value would be based on a concentration that is already estimated. This is not likely to be a precise estimating method.

METHOD 10--LINEAR FUNCTION OF VISIBILITY (EXTINCTION)

Trijonis has recently published reports which have indicated high correlation between IP or FP concentrations and concurrent airport visibility-relative humidity readings.[3,11] Originally, the relationship could only be used to predict visibility from IP or FP data. With recent modifications, these predictive equations now have reasonable capability of estimating IP and FP concentrations, both annual average and daily values, from visibility data. Much of Trijonis' success to date has been with data for the eastern United States. However, one publication presents a map with median annual visual range at suburban/nonurban locations across the United States for use in estimating background levels of fine particles.[11] This map is reproduced in Figure 1.

The predictive models (annual average or max 24-h) for the eastern United States are:

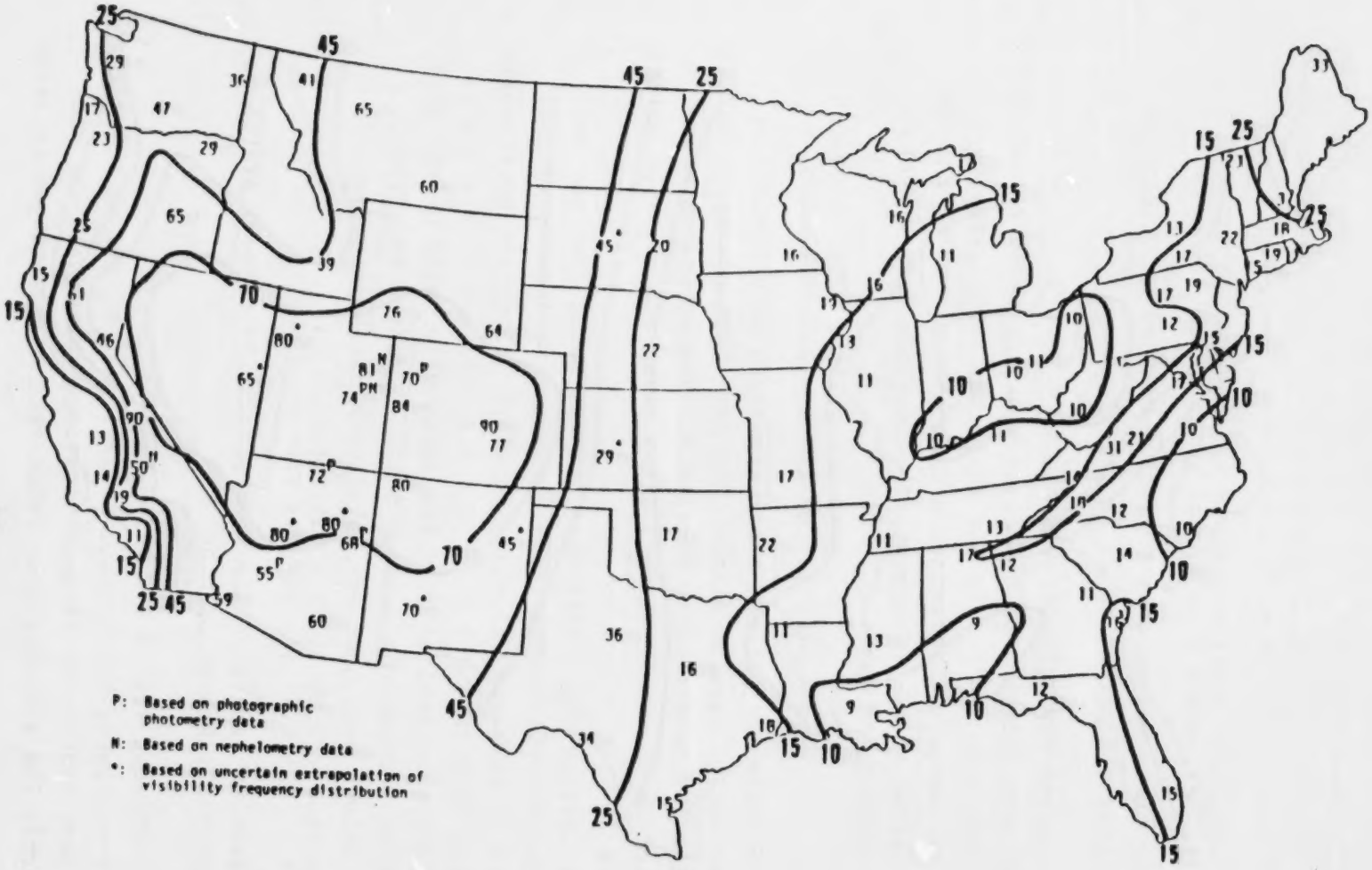

Figure 1. Median annual visual range (in miles) at suburban/nonurban locations in the United States.

Source: Trijonis, J., August 1981, p. 5.

$$IP = 23.8 + 8.7\ B$$
$$FP = 8.4 + 7.5\ B$$

where B = Extinction coefficient, in 10^4 m
= 18.75/V, where V is visual range in mi

The standard error values that Trijonis obtained in developing these equations are presented in Section 4.

METHOD 11--LINEAR FUNCTION OF (VISIBILITY + TSP)

In his most recent report, Trijonis has proposed a predictive model based on visibility and TSP data.[3] This was found to produce lower percentage standard errors than either of the two variables tested alone. The specific equations (for annual average or high 24-h) are:

$$IP = -0.7 + 0.55\ (17\ B + 0.6\ TSP)$$
$$FP = -4.1 + 0.68\ (10\ B + 0.3\ TSP)$$

As with the preceding method, these equations were limited by Trijonis to use in eastern states, but have been evaluated on both the E and W data sets in Section 4. The equations above were applied to the 16 IP Network sites using visual range values from Figure 1.

While testing the W data sets, it was noted that the two linear regression equations above consistently under-predicted both IP and FP measured values. Therefore, alternate equations--still of the form IP = a + b (17 B + 0.6 TSP) and FP = a + b (10 B + 0.3 TSP)--were derived from the relatively small W data sets (primary plus independent data). These alternate equations, presented below, were then evaluated with the W data sets:

$$IP_w = -2.6 + 0.86\ (17\ B + 0.6\ TSP)$$
$$FP_w^w = 0 + 0.61\ (10\ B + 0.3\ TSP)$$

The results of evaluating this predictive methods are shown in Appendix Table A-5 through A-7.

METHOD 12--DEFAULT VALUES FOR FP IN THE WEST

After reviewing the FP data in Tables 3, 5, and 6, it became apparent that background FP concentrations throughout the west are uniformly low and vary over relatively narrow ranges in large

geographic areas. One possible method of estimating background that has often been suggested is for researchers to provide single-valued concentrations that would be appropriate for designated geographic areas. By averaging the arithmetic mean FP values reported in the above-mentioned three tables and rounding, the following "default" values were obtained:

6 Great Plains states - 10.0 $\mu g/m^3$
8 Rocky Mountain states - 4.0 $\mu g/m^3$
3 Pacific Coast states - 13.0 $\mu g/m^3$

The resulting predictive method is to simply select the appropriate default FP background value based on the state in which the analysis area occurs. The method is not expected to provide as precise an estimate as some of the other methods, but the systematic evaluation procedure being used in this study permits it to be ranked with the others for comparative purposes. Should it prove to be reasonably precise, default values could also be developed for IP and for high 24-h background concentrations. This method is expected to be less precise than other methods because the resulting values are constants rather than a linear regression equation from a line of best fit.

The large difference in background concentrations between the Rocky Mountain states and other western states should be noted. The difference in concentrations is even more striking when it is between the Western Particulate Characterization Study (WPCS), as shown in Table 4, and western sites in the IP Network or other studies. One explanation for this distinct disparity is that the sampling equipment in the two networks sample different size ranges or with different efficiencies. The WPCS employed stacked filter units and the IP Network and other studies used dichots. Upon further investigation of extensive unpublished data, differences in samplers were rejected as the primary reason for the large deviation in ranges of concentrations. Instead, they are attributed almost entirely to siting criteria: the WPCS located its samplers in very remote forested areas such as

National Wildlife Refuges, while the IP Network and other studies generally placed background sites in nonurban locations at the edge of urban areas.

METHOD 13--AVERAGE OF VALUES OBTAINED FROM TWO OR MORE OF THE ABOVE METHODS

In statistics, as more samples are taken from a population and more sample means become available to estimate the true population mean, the average of the sample means approaches the population mean and the standard deviation of the sample means decreases. Analogously, if two or more independent estimates of background are averaged, the resulting value should approach the "true" background for an area.

Some preselection of the methods to be used in averaging has been done so that a) the averaging procedure is practical in terms of input requirements and b) methods which have low standard errors are employed. Based on preliminary analyses results from the best 2 or 3 methods identified (lowest $S_{y,x}$) were merely added together and averaged. The method results to be added are summarized as follows:

ann av IP = 1/3 [Method 2 + Method 6 + Method 11]

max 24-h IP = no equation

ann av FP = 1/2 [Method 6 + Method 11]

max 24-h FP = 1/3 [Method 2 + Method 8 + Method 9]

Each of the component methods must be completed prior to the averaging. The analysis of the averaging method is presented in Tables A-8 through A-10. This method is only applicable in the east.

SECTION 4
RESULTS

The predictive equations for each estimating method were determined as described in Section 2. The resulting equations for predicting the four background values of interest are presented in Table 7. In cases where the equations for eastern and western locations were significantly different (at the 0.05 level), the two stratified equations are shown. Also, if a similar predictive equation was previously reported in the literature, it is shown in the table for purposes of comparison.

It is important to note that, with the exception of Method 1 (use of IP dichot data), all the equations or models estimate IP rather than PM_{10}. This situation occurs because measured data are not available to check the predictive abilities of a model for PM_{10}. To convert a predicted annual IP value to PM_{10}, it is recommended that the ratios 0.88 and 0.77 be used in the east and west, respectively. Corresponding values for the high 24-h case are 0.90 (E) and 0.78 (W). These four ratios, split by time period and geographic area, agree better with data collected in 1982 in the IP Network than the previously-proposed IP times 0.90 or FP plus 0.80 IP.

The data used to generate most of the equations in Table 7 are not shown in this report. For example, no SSI data, sulfate and nitrate concentrations, or suburban residential site data are presented. The primary reason for not including all these data sets is that different IP and FP data subsets from those shown in Table 3 were employed in several of these analyses to obtain correspondence and the required data presentation would have been unwieldy and confusing. The data and results for Methods 1, 2, 11, and 13 have been summarized in Appendix A.

The purpose of this study is to evaluate the alternative models in Table 7. This evaluation has been done through the use

TABLE 7. PREDICTIVE EQUATIONS FOR ESTIMATING BACKGROUND IP AND FP

Predictive method	Proposed equation for estimating background concentration			
	Ann av IP	High 24-h IP	Ann av FP	High 24-h FP
1. Dichot data, adjust IP to PM_{10}[a]	E 0.88 IP^d W 0.77 IP^d FP + 0.8 IP or 0.9 IP^d (Ref. 5) 0.8 IP^d (Ref. 12)	E 0.90 IP^d W 0.78 IP^d FP + 0.8 IP or 0.9 IP^d (Ref. 5) 0.8 IP^d (Ref. 12)	Measured FP	Measured FP
2. TSP times constant ratio	0.61 TSP 0.61 TSP (Ref. 1) 0.61 TSP (Ref. 2)	0.75 $TSP_{24\text{-}h}$	E 0.40 TSP W 0.28 TSP + 0.30 TSP (Ref. 2)	E 0.58 $TSP_{24\text{-}h}$ W 0.23 $TSP_{24\text{-}h}$
3. Nearby suburban residential site	IP_{SR}	Same as ann av	FP_{SR}	Same as ann av
4. $IP_{suburban}(TSP_{rural}/TSP_{suburban})$	$IP_{SR}(TSP_R/TSP_{SR})$	Same as ann av	-	-
5. IP SO_4 + NO_3 at suburban residential site times constant ratio	0.36 $(IP\ SO_4 + NO_3)_{SR}$	-	0.50 $(FP\ SO_4 + NO_3)_{SR}$	-
6. TSP SO_4 + NO_3 times constant ratio	E 1.81 $(TSP\ SO_4 + NO_3)$ W 4.65 $(TSP\ SO_4 + NO_3)$	-	E 1.20 $(TSP\ SO_4 + NO_3)$ W 1.80 $(TSP\ SO_4 + NO_3)$	-
7. SSI times constant ratio	0.75 SSI	0.90 $SSI_{24\text{-}h}$	-	-
8. High 24-h = ann av times constant ratio	-	2.68 $IP_{ann\ av}$	-	2.60 $FP_{ann\ av}$
9. High 24-h IP times constant ratio	-	-	-	E 0.67 $IP_{24\text{-}h}$ W 0.27 $IP_{24\text{-}h}$
10. Linear function of visibility	E 23.8 + 8.7 B (Ref. 3)	Same as ann av	E 8.4 + 7.5 B (Ref. 3)	Same as ann av
11. Linear function of (visibility + TSP)	E -0.7 + 0.55 (17 B + 0.6 TSP) (Ref. 3) W -2.6 + 0.86 (17 B + 0.6 TSP)	Same as ann av	E -4.1 + 0.68 (10 B + 0.3 TSP) (Ref. 3) W 0.61 (10 B + 0.3 TSP)	Same as ann av
12. Narrow range of values in west	-	-	10.0 in Great Plains 4.0 in Rocky Mountains 13.0 on Pacific Coast	-
13. Average of values from some methods above	E 1/3[0.61 TSP + 1.81 $(TSP\ SO_4 + NO_3)$ -0.7 + 0.55 (17 B + 0.6 TSP)]	-	E 1/2[1.20 $(TSP\ SO_4 + NO_3)$ -4.1 + 0.68 (10 B + 0.3 TSP)]	E 1/3[0.58 $TSP_{24\text{-}h}$ + 0.67 $IP_{24\text{-}h}$ + 2.60 $FP_{ann\ av}$]

[a] These equations are for predicting PM_{10} from total IP and were derived from collocated PM_{10} and IP monitors at urban and suburban sites.

E = Eastern sites
W = Western sites

of standard errors of estimate calculated for each model. The standard errors of estimate, expressed as fractions of the mean measured value ($S_{y,x}/\bar{Y}_m$), are presented in Table 8. For each applicable method, $S_{y,x}/\bar{Y}_m$ is reported first for the data set from which it was developed (usually the IP Network), then for any independent data set on which it was tested, and finally for any urban data sets reported in the literature. Also, $S_{y,x}/\bar{Y}_m$ is stratified by E and W subsets if separate equations are given for E and W.

With the exception of Method 1, the standard error values in Columns 2 through 7 of Table 8 represent only the prediction of an IP background concentration and do not include the additional error involved in converting the estimated IP value to PM_{10}. Similarly, the standard error values for Methods 7 and 8 do not include a combined error term even though they require one estimated background concentration as input in order to predict another background value.

GENERAL OBSERVATIONS

As anticipated, the models for predicting annual averages generally had lower standard errors of estimate than those for predicting maximum 24-h values. This result follows from the statistical observation that measures of central tendency can be estimated more closely than extreme values or single data points in a distribution.

Also, IP values were estimated more closely than corresponding FP values. It is possible that much of this added error is associated with measurement problems with FP, especially at background sites. For many individual samples, the weight of FP material collected on the Teflon filter in 24 hours is only a few times the error level of the gravimetric analysis procedure. The hydroscopic nature of the FP samples and lack of bonding of the collected particles to the filter surface further increase the measurement error. The level of measurement error is indicated in Table 8 by the standard errors of 0.21 0.17 in side-by-side

sampling for FP with IP dichotomous and PM_{10} dichotomous samplers (Method 1 Columns 8 and 11). The annual data from which the 0.21 value was calculated can be found in Appendix Table A-1. Some portion of the 0.21 value can be attributed to the different sample sizes used in the analysis for the two samplers. as evidenced by the lower value obtained for the high 24-h IP analysis using paired data (0.17).

Although these two samplers have the same particle size cutpoint for FP, significant sampling imprecision does exist for these small particles and related low concentrations. It is probable that collocated samplers of either type would show equivalent imprecision for the FP measurements. This is not an indictment of either sampler or the basic sampling mechanism. Rather, the combination of potential handling problems and the small amount of collected mass for the FP fraction (near the laboratory measurement threshold) require that analyses of FP data also consider the precision of the measurements.

In contrast, the standard errors for PM_{10} are only 0.12, for annual data and 0.07 for the high 24-h value, including the error due to variability in PM_{10} to IP ratios from site to site (also Method 1). A very important observation here is that several of the predictive methods for IP have a $S_{y,x}/\bar{Y}_m$ in the range of 0.10 to 0.15, or about the same as the measurement error.

The standard errors of estimate reported in the literature appear to be about the same as the standard errors determined in this study. This result is partly due to the fact that IP Network data have been the basis for all the analyses. However, the prior studies used mostly urban data, while the present study employed primarily nonurban data.[1,6,7]

The models that had significantly different equations for eastern and western sites all had lower standard errors at the eastern sites. This result is hypothesized to be due to the different major contributing sources to background particulate concentrations in the east and west. Eastern background is presumed to be related to uniform, predictable variables such as

TABLE 8. STANDARD ERRORS OF ESTIMATE FOR PREDICTIVE METHODS

Predictive method	Standard error of estimate, percent ($S_{y,x}/\bar{Y}_m$)											
	Ann av IP			High 24-h IP			Ann av FP			High 24-h FP		
	Primary data	Independent data	Other study	Primary data	Independent data	Other study	Primary data	Independent data	Other study	Primary data	Independent data	Other study
1. Dichot data, adjust IP to PM_{10}	0.12[a]	-	-	0.07[a]	-	-	0.21[b]	-	-	0.17[b]	-	-
2. TSP times constant ratio	0.16	0.17	0.16 (Ref. 3)	0.21	0.38	0.31 0.29	0.29	0.26	0.30 0.26	E 0.29 W 0.90	0.43	0.45 (Ref. 3)
3. Nearby suburban residential site	0.60	-	-	0.58	-	-	0.73	-	-	0.78	-	-
4. $IP_{suburban}(TSP_{rural}/TSP/suburban)$	0.53	-	-	0.97	-	-	-	-	-	-	-	-
5. IP SO_4 + NO_3 at suburban residential site times constant ratio	0.48	-	-	-	-	-	0.40	-	-	-	-	-
6. TSP SO_4 + NO_3 times constant ratio	E 0.10 W 0.51	-	-	-	-	-	E 0.16 W 0.33	-	-	-	-	-
7. SSI times constant ratio	0.17		0.18 (Ref. 1)	0.20	-	-	-	-	-	-	-	-
8. High 24-h = ann av times constant ratio	-	-	-	0.32	0.22	-	-	-	-	0.33	0.28	-
9. High 24-h IP times constant ratio	-	-	-	-	-	-	-	-	-	E 0.29 W 0.67	-	-
10. Linear function of visibility	-	-	E 0.25 (Ref. 3)	-	-	E 0.42 (Ref. 3)	-	-	E 0.19 (Ref. 3)	-	-	E 0.41 (Ref. 3)
11. Linear function of (visibility + TSP) with new linear eqn.	E 0.18 W 0.37 W 0.20	E 0.10 -	E 0.12 (Ref. 3) -	- - -	- - -	E 0.29 (Ref. 3) - -	E 0.19 W 0.22 W 0.25	E 0.27 W 0.48 -	E 0.16 (Ref. 3)	- - -	- -	E 0.41 (Ref. 3)
12. Narrow range of values in west	-	-	-	-	-	-	W 0.49	-	-	-	-	-
13. Average of values from some methods above	-	E 0.13	-	-	-	-	-	E 0.13	-	E 0.25 W 0.54	E 0.18	-

[a] Error in predicting PM_{10} from total IP at urban sites.
[b] Indication of sampling precision for FP measurements from an IP dichot and a PM_{10} dichot at the same location.

E = Eastern sites
W = Western sites

sulfates, transport, and visibility. Western background is possibly more a function of erratic, specific-event variables such as wind storms, biological debris, large-scale burning, and agricultural activity.

OBSERVATIONS BY METHOD

Method 1--Dichotomous Sampler Data

The standard errors for predicting PM_{10} and FP from IP dichotomous data are about the lowest of any method. It is therefore the preferred method for both size fractions.

Method 2--TSP Times Constant Ratio

TSP has been shown to be a highly variable estimator of IP for an individual site or a single measurement.[12] This analysis and two earlier studies have defined consistent relationships between mean annual TSP and IP data for large data sets.[1,2] In fact, this study has found an identical annual relationship for nonurban sites as was found for urban sites. However, as the data in Table 8 shows, the standard errors of estimate for 24-hour data are greater than those for annual data. Further, the standard errors of estimate for 24-hour data from these nonurban sites are lower than those found for other groups of sites. Both of these observations demonstrate the variability inherent in estimating IP concentrations from TSP data.

Methods 3, 4, and 5--Using Suburban Residential Sites

All three of the methods that utilize data from suburban residential sites have poor standard errors. Apparently, there is no close relationship between particulate concentrations measured at suburban and nonurban sites in the same region.

Method 6--TSP Sulfates and Nitrates at Background Sites Times Constant Ratio

At eastern sites where sulfate concentrations are higher than in the west, the sulfate plus nitrate concentrations measured at a background site are a very good indicator of either IP or FP concentrations at that site. Because sulfates and nitrates are not determined for every sample, this method is not applicable for estimating maximum 24-h background concentrations. Also,

the IP Network samples had consistent handling and analysis procedures, which is very important to the reproducibility of sulfate and nitrate measurements. If this consistency is not present in a local data set or different analytical procedures than those of the IP Network are used, the predictive ability of this method would be expected to decline.

Due to the small size of most data sets for TSP sulfates and nitrates, this method is an excellent candidate for averaging with the results of other predictive methods for determining background values (see Method 13).

Method 7--Size Selective Inlet Times Constant Ratio

Although IP measured with a dichot and an SSI should be the same concentration, analysis of side-by-side measurements has shown that the average ratio is only 0.75 when glass fiber filters are used in the SSI. However, that ratio is consistent enough that it can be used to predict IP from the SSI concentration. The $S_{y,x}/\bar{Y}_m$ values of 0.17 and 0.20 for ann av and max 24-h estimates make it a mid-level ranked method. Qualitatively, the method is ranked lower because recent measurements and future measurements taken with an SSI should utilize quartz filters, making this conversion unnecessary. No attempt was made to test SSI concentrations as a predictor of FP.

Method 8--24-h Background Value as Constant Ratio of Corresponding Annual Average Concentration

The standard error values for estimating the high 24-h concentration as a constant ratio of the corresponding ann av concentration are marginal when compared with the other values in Table 8. These values do not include any error in deriving the estimate of ann av background values, so the combined error would result in unacceptably large total standard errors.

Method 9--24-h IP Times Constant Ratio

Similarly to Method 8, this method of predicting high 24-h FP from high 24-h IP relies on one estimated value to derive another. For the same reason as above, the standard error values are unacceptably large.

Method 10--Linear Function of Visibility (Extinction)

Using the relationship between IP or FP and visibility developed by Trijonis, the method was reported to have fairly good predictive ability for ann av IP and FP ($S_{y,x}/\bar{Y}_m$ = 0.25 and 0.19), but not good ability for high 24-h values ($S_{y,x}/\bar{Y}_m$ = 0.42 and 0.41). One advantage of this method for "backup" use is that background concentrations can be calculated for any desired location based on the visibility data in Figure 1.

Method 11--Linear Function of (Visibility + TSP)

This recently-developed model[3], a combination of Methods 2 and 10, produces lower standard errors for both IP and FP background estimates than either of the component methods. TSP values for background are available for almost every region of the country and an average annual nonurban visibility estimate can be obtained for any location from Figure 1; therefore, this method can be employed virtually anywhere. If first order NWS airport visibility data at a nearby nonurban location are available for specific dates of interest, this method could also be used to estimate max 24-h IP and FP values.

Because of its better predictive ability, this method should supersede Method 10 except in rare instances. However, it should probably be ranked below Method 2 for IP.

Separate equations were used to improve this method's predictive capability at western sites. The amount of data available to derive these equations was relatively small. Therefore, if additional data become available in the near future, the coefficients in the equations should be requantified. This modification should be a high priority item because only one other method (dichot data) appears to be acceptable for predicting ann av FP in the west.

Method 12--Default Values for FP in the West

This preliminary attempt to develop "default" background values almost comparable in precision to direct measurements did not prove successful. However, further work in this area is also encouraged. For example, stratification of background sites into

subsets of remote and edge of urban area with separate values for each would probably greatly decrease resulting standard error values.

Method 13--Average of Values Obtained from Two or More of the Above Methods

This concept of averaging values from some of the marginal methods above to obtain a better estimate of background is not as simple as the others proposed. Even though the standard error values indicate that it may be the most precise method other than direct dichot measurements, questions still exist as to its applicability and to the analysis results. The primary question concerns the use of sulfate and nitrate data in the method, because of the problems of artifact formation discussed previously. For this reason, the method loses some of its high ranking on a qualitative basis. Also, it is only applicable in the east.

SECTION 5
CONCLUSIONS AND RECOMMENDATIONS

RANKING OF PREDICTIVE METHODS

Based on the standard error values reported in Table 8 and nonquantitative information discussed in Section 4, the various methods for predicting background concentrations were ranked relative to one another. The methods with the lowest standard errors of estimates are shown in Table 9.

The methods listed in Table 9 would not all be described as acceptable. For example, neither the size-selective inlet using glass fiber filters nor TSP sulfate and nitrate methods would be recommended because of continuing concerns about their sampling techniques. The visibility relationship with ann av FP would, in most cases, be superseded by the better-fitting visibility-plus-TSP relationship.

A few other methods that ranked high enough to be included in Table 9 probably need further verification. In particular, the method of averaging the results of other methods may be considered spurious by some users. No data were available to test the visibility-plus-TSP method for high 24-h predictive ability, so this ranking is based solely on a published reference.

<u>At this time, only three of the methods evaluated can be recommended without reservation</u>:

1. IP or PM_{10} sampler measurements at an acceptable background site
2. TSP data times a constant ratio to estimate PM_{10}
3. Linear function of visibility-plus-TSP to estimate ann av PM_{10} and FP.

TABLE 9. METHODS FOR ESTIMATING SIZE-FRACTIONATED PARTICULATE BACKGROUND CONCENTRATIONS

Method No.	Background value to be estimated			
	Ann av IP	High 24-h IP	Ann av FP	High 24-h FP
1	Dichot data; adjust IP to PM_{10}	Dichot data; adjust IP to PM_{10}	Direct measure	Direct measure
2	0.61 TSP ann av	0.75 TSP 24-h		
11	-0.7 + 0.55 (17 B + .6 TSP) in east -2.6 + 0.86 (17 B + .6 TSP) in west	-0.7 + 0.55 (17 B + .6 TSP 24-h) in east -2.6 + 0.86 (17 B + .6 TSP 24-h) in west	-4.1 + 0.68 (10 B + .3 TSP) in east 0.61 (10 B + .3 TSP) in west	0.33 (0.58 TSP 24-h + 0.67 IP 24-h + 2.60 FP ann av) in east
13	0.33 [0.61 TSP + 1.81 (TSP SO_4 + NO_3) -0.7 + 0.55 (17 B + 0.6 TSP)] in east		0.5 [1.20 (TSP SO_4 + NO_3) -4.1 + 0.68 (10 B + .3 TSP)] in east	
7	0.75 SSI	0.90 SSI 24-h		
6	1.81 (TSP SO_4 + NO_3) in east		1.20 (TSP SO_4 + NO_3) in east	

No method other than direct measurement was found that could be recommended for estimating FP high 24-h. To provide some means of obtaining an estimate, the averaging method (Method 13) is the best available for eastern areas. FP measurements are primarily helpful in receptor modeling and for estimating the long range transport component of measured data.

The methods shown in Table 9 other than those recommended should only be used under special circumstances, and should be accompanied by a detailed justification.

PROCEDURE FOR ADJUSTING BACKGROUND CONCENTRATIONS

The few number of acceptable methods simplifies the adjustment process, which is outlined below. This process assumes an appropriate TSP or IP surrogate background value has been obtained and that value must be used in the equations. Determining which TSP or IP data to use was beyond the scope of this report.

1. If IP or PM_{10} data are available for a background site in or near the analysis area, they are unquestionably the first choice. As indicated in the introduction to this report, there are very few IP or PM_{10} samplers located at background sites.

   PM_{10} ann av = 0.88 measured IP ann av in east
   = 0.77 measured IP ann av in west

   PM_{10} high 24-h = 0.90 measured IP high 24-h in east
   = 0.78 measured IP high 24-h in west

   FP ann av = measured FP ann av

   FP high 24-h = measured FP high 24-h

2. For estimating PM_{10} background, TSP background site data are the second choice. TSP data (alone) are not recommended for estimating FP.

   PM_{10} ann av = 0.88 (0.61) TSP ann av in east
   = 0.77 (0.61) TSP ann av in west

   PM_{10} high 24-h = 0.90 (0.75) TSP high 24-h in east
   = 0.78 (0.75) TSP high 24-h in west

3. The second choice for FP ann av and third for PM_{10} is a linear equation with visibility and TSP terms (Method 11). This method can only be used to estimate high

24-h PM_{10} if appropriate nonurban visibility data for days corresponding to high TSP measurements can be obtained for the analysis area.

This method requires TSP input but has larger errors than just using TSP to estimate PM_{10}. Therefore, the only situation in which it is anticipated that visibility-plus-TSP would be utilized to estimate PM_{10} background is if the TSP background value for an area is outside the normally-accepted range of TSP levels for that region of the U.S., and some means of adjusting this questionable value is desired.

PM_{10} ann av = -0.7 + 0.55 (17 B + 0.6 TSP ann av) in east
= -2.6 + 0.86 (17 B + 0.6 TSP ann av) in west

PM_{10} high 24-h[a] = -0.7 + 0.55 (17 B + 0.6 TSP high 24-h) in east
= -2.6 + 0.86 (17 B + 0.6 TSP high 24-h) in west

FP ann av = -4.1 + 0.68 (10 B + 0.3 TSP ann av) in east
= 0 + 0.61 (10 B + 0.3 TSP ann av) in west

[a]Can only be used if first order NWS airport visibility data at a nearby nonurban location are available for same dates as TSP high 24-h values.

In these equations B = 18.75/V, where V = visual range in miles, obtained from Figure 1 or appropriate airport visibility records.

4. The final choice is only recommended provisionally, to provide some method other than direct measurement to estimate FP high 24-h in <u>eastern</u> areas. It should not be used for western locations.

FP high 24-h = 0.33 (0.58 TSP high 24-h + 0.67 IP high 24-h + 2.60 FP ann av) in east

It should be noted that additional PM_{10} data that could be used to refine the preceding analyses are rapidly becoming available. The EPA document entitled "Procedures for Estimating Probability of Nonattainment of a PM_{10} NAAQS Using Total Suspended Particulates or Inhalable Particulate Data"[12] will be revised in

early 1985 based on this additional PM_{10} data. Method 1, which is currently based on very limited PM_{10} data, may be modified or superseded by the revised document.

OTHER CONSIDERATIONS FOR DETERMINATION OF PM_{10} BACKGROUND

This report has presented several means whereby PM_{10} background concentrations can be determined from other surrogate measured data. The implication of these techniques is that the estimated PM_{10} concentrations will then be treated as if they were measured data. However, no guidance has been included with which to address other considerations for background determinations. As the scope of this study was to provide ways to obtain these surrogate data, such guidance is beyond the scope of the present discussion. Therefore, the following discussion is restricted to identification of rather than resolution of the other key considerations that need to be addressed in the SIP process.

Background air quality in an area includes pollutant concentrations from a variety of sources including 1) natural sources; 2) nearby anthropogenic sources; and 3) unidentified sources[13]. Additional subgroups of these would include: primary vs. secondary emissions; and distinctions between localized and long range sources.

One of the major difficulties in any air quality analysis is to define representative background data for an area in which existing measured data includes the impacts from these diversified sources. These analyses are generally restricted to well-defined areas and require that background concentrations be established for several time periods: annual, seasonal, and 24-hour. In all cases selection of representative background data may be a complicated process. In remote areas there may be no monitoring data to choose from, while near urban areas a multitude of data may be available. The analyst must define a representative site in the study area or create a set of composite data from several sites located within the study area.

Historical data could be evaluated to find a similar time period during which no source impact occurred. These data could then be used for background. In the case of 24-hour analyses certain meteorological criteria could be defined and air quality measurements taken during these conditions used as background.

A number of source apportionment techniques are available that can be used alone or in conjunction with the analyses outlined above. These techniques are used to resolve measured data into its various components. They include: chemical and microscopic analyses, use of FP data trajectory analyses, and mass balance and multivariate analyses.

The methods described herein allow the analyst to obtain estimates of PM_{10} data; however, the other considerations described above must be resolved in order to make adequate use of the results.

RECOMMENDATIONS FOR ADDITIONAL WORK

The major deficiency in the procedure for estimating PM_{10} and FP background concentrations is a method for estimating FP high 24-h values. The most promising prospect is a linear equation with visibility and TSP data, but no individual day visibility data were available during the present study with which to derive such an equation.

An omnipresent problem in performing this study was the small number of background sites nationwide for which size-fractionated particulate data could be obtained. As more such data become available, it may be desirable to redo the analyses and develop revised equations and rankings.

Other recommendations for additional work that would be logical extensions of the present study include:

1. Develop a relatively easy procedure for estimating the split of any background value into components of long-range transport and regionally-generated particulate.

2. Prepare default maps of the United States that provide background values for any location. It appears that the best basis for these maps would be visibility-plus-TSP-relationship that has shown good predictive capability in its testing to date.

3. Develop for presentation with the estimating methods some information on the seasonal variations of PM_{10} and FP background in the east.

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APPENDIX A

CALCULATIONS FOR SELECTED BACKGROUND ESTIMATING METHODS

This appendix presents the results of the analyses for the four highest rated methods (lowest $S_{y,x}$)--Method 1, Method 2, Method 11, and Method 13. The primary reason for showing the results for these four methods only is that different IP and FP data subsets were employed in the other analyses to obtain correspondence and the required data presentation would have been unwieldy and confusing to the reader. Consequently, it was decided that only data for the best methods identified would be included.

Table A-1 presents the results of the annual analyses for Method 1. The first step of the analysis used measured PM_{10} and IP data to determine the relationship between the two measures. Using one year of monitoring data for each of the six sites, the ratio, PM_{10}/IP, was calculated for the annual means. Then the 6 sites were split into East (Birmingham, Buffalo, Philadelphia) and West (Phoenix, Rubidoux, Houston). The three ratios determined for each subgroup were averaged to obtain 0.88 for the three eastern sites and 0.77 for the western sites.

Because no independent data set was available to evaluate the developed relationships, the average for the first two quarters of data was obtained for each site for both the PM_{10} and IP samplers. Both the total concentration and the FP concentration were obtained for each sampler at the sites. Then the 0.88 and 0.77 ratios were applied to measured IP at the sites to calculate an estimated PM_{10} value.

The differences between the estimated PM_{10} values and the measured IP values were calculated as shown in the last column of Table A-1. In a similar manner the differences between measurements of FP were calculated as shown in the fifth column of the table. Finally, the standard errors of estimate were calculated for the two measurements of FP and the two PM_{10} values at each sites (measured and estimated).

TABLE A-1. METHOD 1--ANALYSIS OF PM_{10} VERSUS IP (DICHOTOMOUS SAMPLERS)

Site (nearest urban area)	Sampler	No. of Samples	Concentration, µg/m³				
			Av. FP	Difference	Av. Total	Est. PM_{10}[a]	Difference
Birmingham	PM_{10}	16	35.4	-6.0	65.9		-4.4
	IP	29	29.4		69.9	61.5	
Phoenix	PM_{10}	23	13.3	+5.4	36.7		+4.6
	IP	28	18.7		53.6	41.3	
Rubidoux	PM_{10}	20	55.9	-3.2	85.6		-12.2
	IP	22	52.7		95.3	73.4	
Buffalo	PM_{10}	16	23.8	-0.9	45.0		+0.6
	IP	23	22.9		51.8	45.6	
Philadelphia	PM_{10}	12	25.0	-0.8	35.6		+1.1
	IP	16	24.2		41.7	36.7	
Houston	PM_{10}	9	18.0	+10.3	42.9		+2.5
	IP	6	28.3		58.9	45.4	
			FP = 29.0		PM_{10} = 51.3		

[a] PM_{10} = 0.88 IP in east, 0.77 IP in west

Standard errors of estimate for Table A-1:

For FP--

$\Sigma d^2 = 182.94$

$S_{y,x} = \sqrt{\frac{182.94}{5}}$

$= 6.05$

$\overline{FP} = 29.0$

$\frac{S_{y,x}}{\overline{FP}} = 0.209$

For PM_{10}--

$\Sigma d^2 = 197.18$

$S_{y,x} = \sqrt{\frac{197.18}{5}}$

$= 6.28$

$\overline{PM_{10}} = 51.3$

$\frac{S_{y,x}}{\overline{PM_{10}}} = 0.122$

For the high 24-h PM_{10} concentrations the ratio of PM_{10}/IP was calculated for the five highest measured PM_{10} concentrations at each of the six sites listed in Table A-1. In all cases, the highest measured IP concentration occurred on only one of these five days. Next, the average PM_{10}/IP ratio was calculated for the E and W sites. The average ratios were calculated to be PM_{10} = 0.90 (IP) for the east and 0.78 (IP) for the west. The corresponding ratios were then applied to the highest measured IP value at each site for comparison to the highest measured PM_{10} value at each site. Finally, the standard error of estimate, 0.07, was calculated from the differences between highest measured values and the mean of the highest measured IP values.

The difference between the highest measurements of FP at each site (IP dichot and PM_{10} dichot) and the mean of the highest measured values from the IP dichot were used to calculate a standard error of 0.17 for the two measurements of FP.

Table A-2 presents the results of the Method 2 analysis for annual data and the primary data set (IP network data). In the first step of the analysis the average IP/TSP ratio was calculated as the mean of the daily ratios for each site. For the 16 sites the average ratios varied from 0.46 to 0.78. Next, the mean ratio and standard deviation were calculated for the E and W sites. Application of the t-test showed that there was no significant difference between the average ratio for the two groups (0.594 E and 0.640 W). Consequently, the average ratio (0.61) calculated for all sites was used as the multiplier for TSP to obtain estimated IP concentrations. The mean TSP values for the IP network data were multiplied by 0.61 to obtain the values in Column 4. Finally, the standard error of estimate was calculated for the sites as shown in the table.

In a similar manner the average FP/TSP ratio was calculated for each site. In this case, the resulting constants (0.40 E and 0.28 W) were shown to be significantly different by the t-test. Consequently, the different constants applied to the separate E and W TSP means to obtain the estimated FP concentrations shown

TABLE A-2. METHOD 2--ANALYSIS OF ANNUAL TSP TIMES A CONSTANT RATIO--
PRIMARY DATA SET

Site	E or W	No. of Samples	Av. Concentration, µg/m³					
			Est. IP= 0.61 TSP	Meas. IP	Absolute diff.	Est. FP= 0.40 TSP (E) 0.28 TSP (W)	Meas. FP	Absolute diff.
Mtn. Brook	E	73	32.6	28.0	4.6	21.3	19.2	2.1
Litchfield	E	36	21.7	16.2	5.5	14.1	10.1	4.0
Braidwood	E	42	37.6	27.1	10.5	24.5	16.4	8.1
Acadia	E	30	12.0	12.7	0.7	7.8	8.3	0.5
Angola	E	50	22.3	26.5	4.2	14.5	18.0	3.5
RTP 101	E	37	26.6	23.7	2.9	17.4	19.0	1.6
RTP 102	E	63	22.6	23.6	1.0	14.8	15.1	0.3
Medina	E	24	29.4	31.3	1.9	19.2	19.9	0.7
Reston	E	94	27.1	27.5	0.4	17.7	18.8	1.1
Carefree	W	61	27.9	23.3	4.6	12.7	7.0	5.7
Marshalltown	W	56	29.2	31.6	2.4	13.2	14.5	1.3
Winnemucca	W	67	33.8	29.7	4.1	15.3	8.7	6.6
Sauvie	W	65	21.5	27.6	6.1	9.8	13.5	3.7
Clint	W	87	47.5	49.6	2.1	21.6	13.3	8.3
Seabrook	W	37	33.1	33.7	0.6	15.0	15.6	0.6
Sauvie 2	W	51	24.7	27.0	2.3	11.2	14.1	2.9
Average				27.4			14.5	

Standard errors of estimate for Table A-2:

For IP--

$\Sigma d^2 = 283.97$

$S_{y,x} = \sqrt{\frac{283.97}{15}}$

$= 4.35$

$\overline{IP} = 27.4$

$\frac{S_{y,x}}{\overline{IP}} = 0.159$

For FP--

$\Sigma d^2 = 271.96$

$S_{y,x} = \sqrt{\frac{271.96}{15}}$

$= 4.26$

$\overline{FP} = 14.5$

$\frac{S_{y,x}}{\overline{FP}} = 0.294$

in Column 7. Finally, the standard error of estimate was calculated as indicated.

In Table A-3 data from the SURE network and from PEDCo's compilation (Tables 4 and 5) were used to verify the relationships developed for Method 2. Measured mean TSP values for each site were multiplied by the respective constants to obtain IP and FP estimates. Then, the standard errors of estimate were calculated. As can be seen, these results are comparable to the results in Table A-2.

Table A-4 presents the Method 2 results for the high 24-h TSP concentrations. For this analysis the ratio of IP/TSP was calculated for the five highest measured IP concentrations at each site. In all cases, the highest measured TSP concentration occurred on one of these five days. Next the average IP/TSP ratio was calculated for the five highest days. The mean ratios for the E and W sites were then calculated from the individual site means. For both subgroups the average ratio was calculated to be IP = 0.75 (TSP). Then, the 0.75 factor was applied to the highest measured TSP value to obtain the results in Column 3. Finally, the standard error of estimate was calculated.

For FP 24-h concentrations the ratios between the highest measured FP and TSP concentrations were calculated for each site. Then, the average ratios for the E and W subgroups were determined to be 0.577 E and 0.230 W. Application of the t-test showed that the difference in constants was significant. The highest measured TSP values were multiplied by the appropriate E or W factor to obtain the results in Column 6. Then, the differences between FP estimates and highest measured FP value were calculated. Finally, the standard error of estimate shown in Table A-4 was calculated.

Also shown in Table A-4 is a verification of the procedure using SURE network data. The appropriate constants for high 24-h IP and FP were applied to the E and W sites to obtain the data in the table. The results of the two analyses compare favorably for FP but not for IP.

TABLE A-3. METHOD 2--ANALYSIS OF ANNUAL TSP TIMES A CONSTANT RATIO--
INDEPENDENT DATA SET

Site	E or W	Av. concentration, µg/m³					
		Est. IP= 0.61 TSP	Meas. IP	Absolute diff.	Est. FP= 0.40 TSP (E) 0.28 TSP (W)	Meas. FP	Absolute diff.
Montague	E	13.4	23	9.6	8.8	17	8.2
Scranton	E	35.4	29	6.4	23.1	18	5.1
Indian River	E	21.4	29	7.6	13.9	19	5.1
Duncan Falls	E	25.6	31	5.4	16.7	20	3.3
Rockport	E	33.6	37	3.4	21.9	23	1.1
Giles Co.	E	26.2	29	2.8	17.1	19	1.9
Ft. Wayne	E	24.4	28	3.6	15.9	20	4.1
RTP	E	22.0	28	6.0	14.3	20	5.7
Lewisburg	E	18.3	22	3.7	11.9	16	4.1
Dodge Rd.	W	16.6	14.7	1.9			
Anaconda	W	31.8	39.3	7.5	14.5	15.5	1.0
St. Louis 1	W	32.9	31.0	1.9	15.0	16	1.0
St. Louis 2	W	33.6	33.0	0.6	15.2	17	1.8
St. Louis 3	W	32.3	29.0	3.3	14.7	16	1.3
St. Louis 4	W	36.6	40.0	3.4			
St. Louis 5	W	41.5	35.0	6.5			
St. Louis 6	W	36.6	34.0	2.6			
St. Louis 7	W	33.6	28.0	5.6			
Angola	E	28.0	33.0	5.0			
Sterling For.	E	13.7	15.9	2.2			
Carus	W				8.9	16.2	7.3
Lebanon	W				12.0	13.1	1.1
Corvallis	W				8.9	15.5	6.6
Average			29.4			17.6	

Standard errors of estimate for Table A-3:

For IP--

$\Sigma d^2 = 490.74$

$S_{y,x} = \sqrt{\frac{490.74}{19}}$

$= 5.082$

$\overline{IP} = 29.4$

$\frac{S_{y,x}}{\overline{IP}} = 0.173$

For FP--

$\Sigma d^2 = 306.07$

$S_{y,x} = \sqrt{\frac{306.07}{15}}$

$= 4.52$

$\overline{FP} = 17.6$

$\frac{S_{y,x}}{\overline{FP}} = 0.257$

TABLE A-4. METHOD 2--ANALYSIS OF MAXIMUM MEASURED TSP TIMES A CONSTANT RATIO

Site	E or W	Maximum concentration, µg,m³					
		Est. IP= 0.75 TSP 24-h	Meas. IP 24-h	Absolute diff.	Est. FP= 0.58 TSP (E) 0.23 TSP (W)	Meas. FP 24-h	Absolute diff.
Mtn. Brook	E	69	55.0	14.0	53.0	37.3	15.7
Litchfield	E	52	67.3	15.3	40.2	55.8	15.6
Braidwood	E	75	69.5	5.5	58.0	38.6	19.4
Acadia	E	34	38.0	4.0	25.7	33.1	7.4
Angola	E	64	59.8	4.2	48.8	59.8	11.0
RTP 101	E	62	40.8	21.2	47.3	31.3	16.0
RTP 102	E	64	60.3	3.7	49.9	45.5	4.4
Medina	E	60	49.8	10.2	46.3	49.8	3.5
Reston	E	59	66.0	7.0	45.8	49.5	3.7
Carefree	W	74	68.0	6.0	22.6	12.1	10.5
Marshalltown	W	93	80.2	12.8	28.4	23.0	5.4
Winnemucca	W	200	158.5	41.5	61.4	21.3	40.1
Sauvie	W	82	76.5	15.5	26.1	43.0	16.9
Clint	W	194	181.1	12.9	59.6	31.0	28.6
Seabrook	W	66	73.6	7.6	20.2	43.1	22.9
Average			76.3			38.3	

(continued)

Table A-4 (continued)

Site	E or W	Maximum concentration, μg,m³					
		Est. IP= 0.75 TSP 24-h	Meas. IP 24-h	Absolute diff.	Est. FP= 0.58 TSP (E) 0.23 TSP (W)	Meas. FP 24-h	Absolute diff.
Montague	E	62	92	30	47	68	21
Scranton	E	163	102	61	125	81	44
Indian River	E	69	90	21	53	63	10
Duncan Falls	E	122	76	46	94	47	47
Rockport	E	148	120	28	114	86	28
Giles Co.	E	70	65	5	54	51	3
Ft. Wayne	E	76	84	8	58	61	3
RTP	E	74	69	5	57	50	7
Lewisburg	E	50	47	3	38	53	15
Average			82.8			62.2	

Standard errors of estimate for primary data:

For IP--

$\Sigma d^2 = 3496.66$

$S_{y,x} = \sqrt{\frac{3496.66}{14}}$

$= 15.8$

$\overline{IP}\ max = 76.3$

$\frac{S_{y,x}}{\overline{IP}\ max} = 0.207$

For FP--

$\Sigma d^2 = 4718.67$

$S_{y,x} = \sqrt{\frac{4718.67}{14}}$

$= 18.36$

$\overline{FP}\ max = 38.3$

$\frac{S_{y,x}}{\overline{FP}\ max} = 0.479$

Standard errors of estimate for independent data for Table A-4:

For IP--

$\Sigma d^2 = 8085$

$S_{y,x} = \sqrt{\frac{8085}{8}}$

$= 31.8$

$\overline{IP}_{max} = 82.8$

$\frac{S_{y,x}}{\overline{IP}_{max}} = 0.384$

For FP--

$\Sigma d^2 = 5762$

$S_{y,x} = \sqrt{\frac{5762}{8}}$

$= 26.8$

$\overline{FP}_{max} = 62.2$

$\frac{S_{y,x}}{\overline{FP}_{max}} = 0.431$

Table A-5 presents an evaluation of the relationship developed by Trijonis (Method 11). For each site, the median annual visual range (V) was estimated from Figure 1. Then the extinction coefficient (B) was calculated. Using the measured TSP annual arithmetic mean at each site, estimates of IP and FP mean concentrations were obtained using the referenced relationships. Finally the standard errors of estimate were calculated for the E and W sites for both IP and FP. As indicated in the table, the method is most appropriate for the east. For the western sites, FP estimates are better than IP estimates.

Table A-6 presents another analysis of Method 11, using data from the SURE network and for 6 selected western sites. Similarly to what was described for Table A-5, estimates of IP and FP concentrations were obtained from measured TSP concentrations. Again, the results for eastern sites are better than for the western sites.

Table A-7 presents the analysis results of the alternative equations developed for Method 11. The coefficients in the alternate equations were derived from the small W data sets using linear regression. The calculated value (17B + 0.6TSP) or (10B + 0.3TSP) was used for the x-value. The measured IP or FP value was used as the y-value. New coefficients for the equations were obtained from the regression equations. As is evident in the results, the alternate equations yield a better prediction for IP and FP for western sites than the original equations.

Also included in Table A-7 are equivalent ranges of estimated IP and FP values for the various areas of the west.

Table A-8 presents the results of Method 13 which involves taking an average of results obtained from three different methods. In this method the estimated IP annual average concentrations are calculated separately for Methods 1, 6, and 11 for 9 eastern sites. For each site the average of the three estimated values is obtained. Finally, the standard error of estimate is calculated. As indicated by the result, this averaging of three results yields a relatively low standard error of estimate.

TABLE A-5. METHOD 11--ANALYSIS OF (VISIBILITY AND TSP)--
PRIMARY DATA SET

Site	E or W	V, mi.	B= 18.75/V	TSP µg/m³	Av. Concentration, µg/m³					
					Est. IP= -0.7+0.55 (17B+0.6TSP)	Meas. IP	Absolute diff.	Est. FP= -4.1+0.68 (10B+0.3TSP)	Meas. FP	Absolute diff.
Mtn. Brook	E	12	1.56	53.4	31.5	28.0	3.5	17.4	19.2	1.8
Litchfield	E	20	0.94	35.5	19.8	16.2	3.6	9.5	10.1	0.6
Braidwood	E	13	1.44	61.6	33.1	27.1	6.0	18.3	16.4	1.9
Acadia	E	30	0.62	19.7	11.6	12.7	1.1	4.1	8.3	4.2
Angola	E	12	1.56	36.5	25.9	26.5	0.6	14.0	18.0	4.0
RTP 101	E	10	1.88	43.6	31.3	23.7	7.6	17.6	19.0	1.4
RTP 102	E	10	1.88	37.1	29.1	23.6	5.5	16.3	15.1	1.2
Medina	E	10	1.88	48.2	32.8	31.3	1.5	18.5	19.9	1.4
Reston	E	15	1.25	44.4	25.6	27.5	1.9	13.5	18.8	5.3
Average						24.1			16.1	
Carefree	W	55	0.34	45.7	17.6	23.3	5.7	7.5	7.0	0.5
Marshalltown	W	17	1.10	47.8	25.4	31.6	6.2	13.1	14.5	1.4
Winnemucca	W	70	0.27	55.4	20.1	29.7	9.6	9.0	8.7	0.3
Sauvie	W	25	0.75	35.3	18.0	27.6	9.6	8.2	13.5	5.3
Clint	W	50	0.38	77.9	28.6	49.6	21.0	14.4	13.3	1.1
Seabrook	W	18	1.04	54.3	26.9	33.7	6.8	14.0	15.6	1.6
Average						32.6			12.1	

Standard errors of estimate for Table A-5:

For IP in east--

$\Sigma d^2 = 156.65$

$S_{y,x} = \sqrt{\frac{156.65}{8}}$

$= 4.43$

$\overline{IP}$ east $= 24.1$

$\frac{S_{y,x}}{\overline{IP} \text{ east}} = 0.184$

For IP in west--

$\Sigma d^2 = 742.5$

$S_{y,x} = \sqrt{\frac{742.5}{5}}$

$= 12.19$

$\overline{IP}$ west $= 32.6$

$\frac{S_{y,x}}{\overline{IP} \text{ west}} = 0.374$

For FP in east--

$\Sigma d^2 = 74.3$

$S_{y,x} = \sqrt{\frac{74.3}{8}}$

$= 3.05$

$\overline{FP}$ east $= 16.1$

$\frac{S_{y,x}}{\overline{FP} \text{ east}} = 0.189$

For FP in west--

$\Sigma d^2 = 34.16$

$S_{y,x} = \sqrt{\frac{34.16}{5}}$

$= 2.61$

$\overline{FP}$ west $= 12.1$

$\frac{S_{y,x}}{\overline{FP} \text{ west}} = 0.216$

TABLE A-6. METHOD 11--ANALYSIS OF (VISIBILITY AND TSP)--
INDEPENDENT DATA SET

Site	E or W	V, mi.	B= 18.75/V	TSP, μg/m³	Av. Concentration, μg/m³					
					Est. IP= -7.0+0.55 (17B+0.6 TSP)	Meas. IP	Absolute diff.	Est. FP= -4.1+0.68 (10B+0.3TSP)	Meas. FP	Absolute diff.
Montague	E	11	1.70	22	22.5	23	0.5	11.9	17	5.1
Scranton	E	19	0.99	58	27.7	29	1.3	14.5	18	3.5
Indian River	E	15	1.25	35	22.5	29	6.5	11.5	19	7.5
Duncan Falls	E	10	1.88	42	30.7	31	0.3	17.3	20	2.7
Rockport	E	10	1.88	55	35.0	37	2.0	19.9	23	3.1
Giles Co.	E	14	1.34	43	26.0	29	3.0	13.8	19	5.2
Ft. Wayne	E	12	1.56	40	27.1	28	0.9	14.7	20	5.3
RTP	E	10	1.88	36	28.8	28	0.8	16.0	20	4.0
Lewisburg	E	15	1.25	30	20.9	22	1.1	10.5	16	5.5
Average						26.3			19.1	
Apache NF	W	70	0.27	14.7	6.7	7.3	0.6	0.7	3.2	2.5
Custer NF	W	60	0.31	13.2	6.6	9.0	2.4	0.7	2.9	2.2
Anaconda	W	45	0.42	52.2	20.5	39.3	18.8	9.4	15.5	6.1
Carus	W	20	0.94	32.3	18.8	nd[a]		8.9	16.2	7.3
Lebanon	W	20	0.94	43.3	22.4	nd		11.1	13.1	2.0
Corvallis	W	18	1.04	32.3	19.7	nd		9.6	15.5	5.9
Average									11.1	

[a] nd = not determined

Standard errors of estimate for Table A-6:

For IP in east--

$\Sigma d^2 = 59.94$

$$S_{y,x} = \sqrt{\frac{59.95}{8}}$$

$= 2.74$

$\overline{IP}$ east $= 26.3$

$$\frac{S_{y,x}}{\overline{IP} \text{ east}} = 0.104$$

For IP in west--

Insufficient data

For FP in east--

$\Sigma d^2 = 212.79$

$$S_{y,x} = \sqrt{\frac{212.79}{8}}$$

$= 5.16$

$\overline{FP}$ east $= 19.1$

$$\frac{S_{y,x}}{\overline{FP} \text{ east}} = 0.270$$

For FP in west--

$d^2 = 140.4$

$$S_{y,x} = \sqrt{\frac{140.4}{5}}$$

$= 5.30$

$\overline{FP}$ west $= 11.1$

$$\frac{S_{y,x}}{\overline{FP} \text{ west}} = 0.477$$

TABLE A-7. METHOD 11--ANALYSIS OF (VISIBILITY AND TSP)--
ALTERNATE EQUATIONS FOR WESTERN SITES

Site	V, mi.	B= 18.75/V	TSP µg/m³	Av. Concentration, µm/m³					
				Est. IP= -2.6+0.86 (17B+0.6TSP)	Meas. IP	Absolute diff.	Est FP= 0.61 (10B +0.3 TSP)	Meas. FP	Absolute diff.
Carefree	55	0.34	45.7	26.0	23.3	2.7	10.4	7.0	3.4
Marshalltown	17	1.10	47.8	38.2	31.6	6.6	15.4	14.5	0.9
Winnemucca	70	0.27	55.4	29.9	29.7	0.2	11.8	8.7	3.1
Sauvie	25	0.75	35.3	26.6	27.6	1.0	11.0	13.5	2.5
Clint	50	0.38	77.9	43.2	49.6	6.4	16.6	13.3	3.3
Seabrook	18	1.04	54.3	40.7	33.7	7.0	16.3	15.6	0.7
Apache NF	70	0.27	14.7	8.9	7.3	1.6	4.3	3.2	1.1
Custer NF	60	0.31	13.2	8.8	9.0	0.2	4.3	2.9	1.4
Anaconda	45	0.42	52.2	30.5	39.3	8.8	12.1	15.5	3.4
Carus	20	0.94	32.3		nd		11.7	16.2	4.5
Lebanon	20	0.94	43.3		nd		13.7	13.1	0.6
Corvallis	17	1.04	32.3		nd		12.3	15.5	3.2
Average					27.9			11.6	
Rocky Mtns.	50-70	.27-.38	15-35	9.0-20.7	4-20		4.4-8.7	3-10	
SW Desert	50-70	.27-.38	25-40	14.1-23.3	7-25		6.2-9.6	5-12	
Pacific Coast	20-30	.62-.94	30-40	21.7-31.4	15-30		9.3-13.1	10-15	
Great Plains	20-45	.42-.94	35-45	21.3-33.9	25-35		9.0-14.0	10-15	
Near Mississippi River	15-20	.94-1.25	40-45	31.4-38.4	25-35		13.1-15.9	15	

Standard errors of estimate for Table A-7:

For IP in west--

$\Sigma d^2 = 221.89$

$S_{y,x} = \sqrt{\frac{221.89}{n-2}}$

$= 5.63$

$\overline{IP} = 27.9$

$\frac{S_{y,x}}{\overline{IP}} = 0.201$

For FP in west--

$\Sigma d^2 = 85.19$

$S_{y,x} = \sqrt{\frac{85.19}{n-2}}$

$= 2.92$

$\overline{FP} = 11.6$

$\frac{S_{y,x}}{\overline{FP}} = 0.252$

Note: 2 degrees of freedom are lost in this estimating method because both a and b coefficients in linear regression equation are calculated.

TABLE A-8. METHOD 13--ANALYSIS OF AVERAGING VALUES FROM OTHER METHODS--
ANNUAL AVERAGE IP

Site	Average Concentration, µg/m³					
	Method 1 0.61 TSP	Method 6 1.81 TSP $SO_4 + NO_3$	Method 11 Visibility + TSP	Average	Actual IP	Absolute difference
Mtn. Brook	32.6	25.8	31.5	30.0	28.0	2.0
Litchfield	21.7	--	19.8	20.8	16.2	4.6
Braidwood	37.6	28.0	33.1	32.9	27.1	5.8
Acadia	12.0	14.0	11.6	12.5	12.7	0.2
Angola	22.3	24.5	25.9	24.2	26.5	2.3
RTP 101	26.6	21.8	31.3	26.6	23.7	2.9
RTP 102	22.6	21.3	29.1	24.3	23.6	0.7
Medina	29.4	35.8	32.8	32.7	31.3	1.4
Reston	27.1	30.2	25.6	27.6	27.5	0.1
Average					24.1	

Standard errors of estimate:

For IP--

$\Sigma d^2 = 75.00$

$S_{y,x} = \sqrt{\frac{75.00}{8}}$

$= 3.06$

$\overline{IP} = 24.1$

$\frac{S_{y,x}}{\overline{IP}} = 0.127$

Table A-9 presents the results of the Method 13 analysis for annual average FP concentrations. In a manner similar to that described for Table A-8 the results calculated for Methods 6 and 11 are obtained and averaged. Once again the standard error of estimate is quite low.

Table A-10 presents the Method 13 results for 24-hour FP concentrations. The results of Methods 2, 8 and 9 were averaged for each site. There are three groups of site data in the table. The first group and the third group represent IP network data for E and W sites respectively. The second group includes data from the 9 SURE network sites. As seen in the calculated standard errors of estimate this analysis does not seem to be appropriate for the west and only marginally appropriate for the east.

TABLE A-9. METHOD 13--ANALYSIS OF AVERAGING VALUES FROM OTHER METHODS--
ANNUAL AVERAGE FP

Site	Average Concentration, µg/m³				
	Method 11 Visibility + TSP	Method 6 1.20 TSP SO_4 + NO_3	Average	Actual FP	Absolute difference
Mtn. Brook	17.4	17.0	17.2	19.2	2.0
Litchfield	9.5	--	9.5	10.1	0.6
Braidwood	18.3	18.5	18.4	16.4	2.0
Acadia	4.1	9.2	6.6	8.3	1.7
Angola	14.0	16.2	15.1	18.0	2.9
RTP 101	17.6	14.4	16.0	19.0	3.0
RTP 102	16.3	14.0	15.2	15.1	0.1
Medina	18.5	23.6	21.0	19.9	1.1
Reston	13.5	19.9	16.7	18.8	2.1
Average				16.0	

Standard errors of estimate:

For FP--

$$\Sigma d^2 = 34.29$$

$$S_{y,x} = \sqrt{\frac{34.29}{8}}$$

$$\overline{FP} = 16.0$$

$$\frac{S_{y,x}}{\overline{FP}} = 0.129$$

TABLE A-10. METHOD 13--ANALYSIS OF AVERAGING VALUES FROM OTHER METHODS--
24-HOUR FP

Site	Concentration, µg/m³					
	Method 9 0.67 IP 24-h	Method 2 0.58 TSP 24-h	Method 8 2.6 FP ann av	Average	FP 24-h	Absolute Difference
Mtn. Brook	36.7	53.0	49.9	46.5	37.3	9.2
Litchfield	44.9	40.2	26.3	37.1	55.8	18.7
Braidwood	46.4	58.0	42.6	49.0	38.6	10.4
Acadia	25.3	25.7	21.6	24.2	33.1	8.9
Angola	39.9	48.8	46.8	45.2	59.8	14.6
RTP 101	27.2	47.3	49.4	41.3	31.3	10.0
RTP 102	40.2	49.9	39.3	43.1	45.5	2.4
Medina	33.2	46.3	51.7	43.7	49.8	6.1
Reston	44.0	45.8	48.9	46.2	49.5	3.3
Average					44.5	
Montague	61.4	47.3	44.2	51.0	68	17.0
Scranton	68.0	125.2	46.8	80.0	81	1.0
Indian River	60.0	53.1	49.4	54.2	63	8.8
Duncan Falls	50.7	94.0	52.0	65.6	47	18.6
Rockport	80.0	113.7	59.8	84.5	86	1.5
Giles Co.	43.4	53.7	49.4	48.8	51	2.2
Ft. Wayne	56.0	58.3	52.0	55.4	61	5.6
RTP	46.0	57.1	52.0	51.7	50	1.7
Lewisburg	31.3	38.1	41.6	37.0	53	16.0
Average					62.2	

(continued)

Table A-10 (continued)

Site	Concentration, μg/m³					
	Method 9 0.67 IP 24-h	Method 2 0.58 TSP 24-h	Method 8 2.6 FP ann av	Average	FP 24-h	Absolute difference
Carefree	18.4	22.6	18.2	19.7	12.1	7.6
Marshalltown	21.7	28.4	37.7	29.3	23.0	6.3
Winnemucca	33.3	61.4	22.6	39.1	21.3	17.8
Sauvie	20.7	26.1	35.1	27.3	43.0	15.7
Clint	48.9	59.6	34.6	47.7	31.0	16.7
Seabrook	17.4	20.2	40.6	26.1	43.1	17.0
Average					28.9	

Standard error of estimate for FP:

Primary, east--

$\Sigma d^2 = 988.72$

$S_{y,x} = \sqrt{\frac{988.72}{8}}$

$= 11.12$

$\overline{FP}\ max = 44.5$

$\frac{S_{y,x}}{\overline{FP}\ max} = 0.250$

Independent, east--

$\Sigma d^2 = 1010.74$

$S_{y,x} = \sqrt{\frac{1010.74}{8}}$

$= 11.24$

$\overline{FP}\ max = 62.2$

$\frac{S_{y,x}}{\overline{FP}\ max} = 0.181$

Primary, west--

$\Sigma d^2 = 1228.67$

$S_{y,x} = \sqrt{\frac{1228.67}{5}}$

$= 15.68$

$\overline{FP}\ max = 28.9$

$\frac{S_{y,x}}{\overline{FP}\ max} = 0.542$

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